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Feasibility Study to Determine the Economic and Operational Benefits of Utilizing Unmanned Aerial Vehicles (UAVs)

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Submitted to:
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Table of Contents

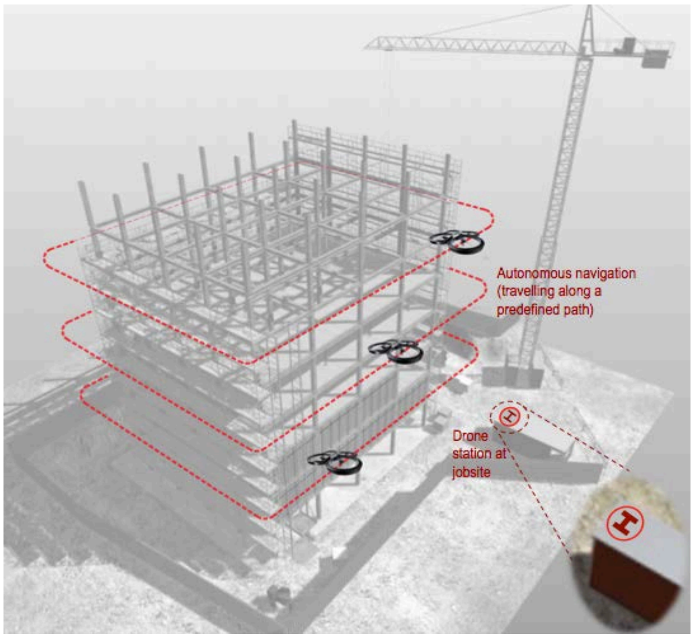
Introduction: 3
Objectives: 7
Work Plan: 8
Expected Results: 13
Deliverables: 13
Implementation: 14
Budget Estimate: 15
Cooperative Features: 19
References: 21
Appendix A. Work Plan Schedule: 23
Appendix B. Supporting Information: 24

Introduction:

Unmanned Aerial Vehicles (UAVs) or “drones” are aircraft that would operate under remote and semi/fully-autonomous control without any pilot onboard. The UAVs can be equipped with various devices such as video cameras, sensors, radars or different communication hardware. Some UAVs are capable of real-time data transfer while others have on-board data storage capabilities. Unmanned aerial vehicles are can move faster than ground vehicles. They can also perform similar tasks that can be done by a manned vehicles but faster, safer and at a lower cost (Puri, 2005). The very first application of these devices was within military missions and now they have their permanent position in the military arsenal (Nisser and Westin, 2006). Some peaceful applications of these devices are in border patrol; search, rescue and damage investigations during/after natural disasters (e.g. hurricanes, earthquakes, tsunamis); locating forest fires or frost conditions in farmlands; monitor criminal activities; mining; advertising; scientific surveys and secure pipelines and offshore oil platforms (Nisser and Westin, 2006, Anand, 2007).

One of the recent cases of using these devices for civilian applications is when a tsunami struck the Fukushima nuclear power plant in Japan on the 11th of March 2011. During that disaster, due to very unsafe conditions at the plant, Tokyo Electric Power (TEPCO) used a US-made micro aerial vehicle called Honeywell T-Hawk™ to photograph the nuclear plant from above. This flying robot had already been used by the US military to find roadside bombs in Iraq (Honig, 2011). Irizarry (PI) and his research team (2012) studied the initial application of UAV technology in the construction industry. In their study, a small-scaled aerial drone was used as a tool for exploring potential benefits to safety managers within the construction jobsite. The drone was an aerial quadricopter that could be piloted remotely using a smart phone, tablet device or a computer. Since the drone was equipped with video cameras, it could provide safety managers with fast access to images as well as real time videos from a range of locations around the jobsite. Figure 1 shows the experimental setup used in the study. The results of this study led to recommendations for the required features of an Ideal Safety Inspection Assistant Drone

(Figure 1). Autonomous navigation, vocal interaction, high-resolution cameras, and collaborative user-interface environment are some examples of those features.



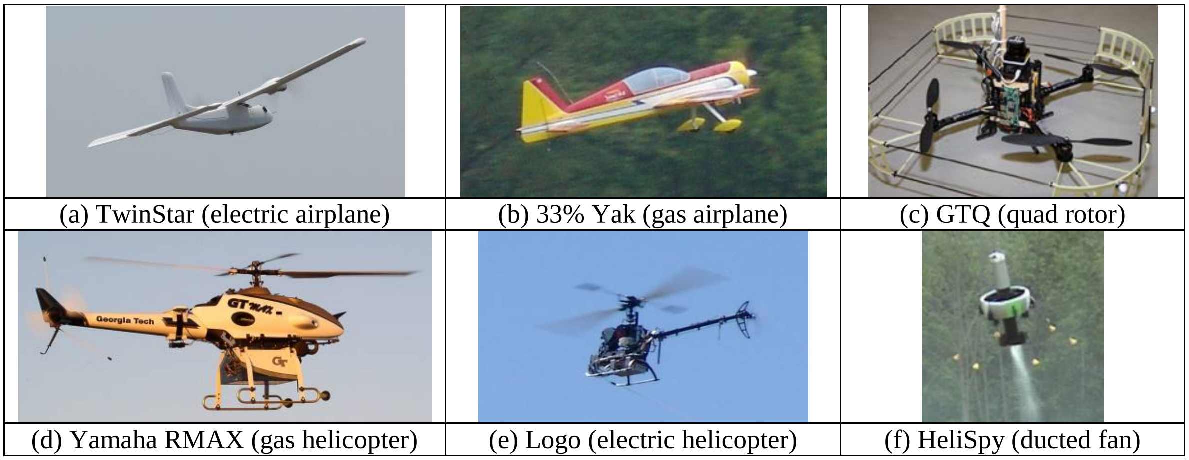
(a) Autonomous navigation using predefined paths or locations

(b) Voice interaction between workers and the drone

(c) Safety manager interacts with workers using the drone and through the iPad

Figure 1. *Ideal safety inspection assistant drone*

Johnson (co-PI), and his research group within the Unmanned Aerial Vehicle Research Facility in the School of Aerospace Engineering at Georgia Tech, have been doing guidance, navigation, and control work for unmanned system for nearly 20 years. The emphasis has been on small unmanned aircraft capable of vertical takeoff and landing (VTOL), with an extreme variety of different aircraft types utilized, some of which are shown in Figure 2. The type of work they do is indicative of the kinds of capabilities that UAVs have gained in that time period, including precision GPS-based navigation, vision-aiding capabilities, automatic real time video processing, and increased autonomy in general.



(a) TwinStar (electric airplane) (b) 33% Yak (gas airplane) (c) GTQ (quad rotor)
(d) Yamaha RMAX (gas helicopter) (e) Logo (electric helicopter) (f) HeliSpy (ducted fan)

Figure 2: *Some of the aircraft that have been utilized for research in the Georgia Tech UAV Research Facility, including a variety of configurations.*

The continuous improvement in the function and performance of UAV systems promotes the need for specific research to integrate this leading edge technology into various applications across Departments of Transportation. DOTs of several states have started using UAV technology for different purposes from tracking highway construction projects and performing structure inventories to road maintenance, monitoring roadside environmental conditions as well as many other surveillance, traffic management or safety issues. Some examples of previous application of UAVs by various DOTs across the country are as following:

The Florida Department of Transportation (UDOT) in collaboration with University of Florida (UFL) used surveillance video from UAV system to monitor remote and rural areas of the state of Florida (Werner, 2003). This project served as a case study on how UAV technology can be used for remote sensing in multimodal transportation applications. *The Virginia Department of Transportation (VDOT)* also cooperated with the National Consortium on Remote Sensing in Transportation (NCRST) to demonstrate the feasibility of an unmanned Airborne Data Acquisition System (ADAS) for real-time traffic surveillance, monitoring traffic incidents and signals, and environmental condition assessment of roadside areas (Carroll and Rathbone, 2002). *The Ohio Department of Transportation (ODOT)* in collaboration with Ohio State University (OSU) performed field experiments in Columbus OH, on the use of UAVs to collect data about freeway

conditions, intersection movement, network paths, and parking lot monitoring. They were using the collected information for space planning and distribution as well as providing quasi real-time information to travelers (Coifman et al., 2003). *The Washington State Department of Transportation (WSDOT)* in collaboration with University of Washington (UW) and the Georgia Tech UAV Research Facility (involving co-PI Johnson) conducted several experiments including the evaluation of UAV use on mountain slopes above state highways to control avalanches or capturing aerial images for data collection and traffic surveillance purposes (McCormack, 2008). Furthermore, *the Utah Department of Transportation (UDOT)* in collaboration with Utah State University (USU) Hydraulic Lab used UAV systems to take high-resolution pictures of highways to inventory their features and conditions at a very low cost and in short time. The pictures taken by UAVs also helped to improve "UDOT geographic information systems (GIS) databases with photos of ongoing and recent highway construction, fish passage culvert locations, wetlands and noxious weeds along highway corridors, and highway structures and road maintenance issues" (TRB, 2012).

The Federal Aviation Administration (FAA) seeks to integrate UAVs into the nation's air transportation system for civilian and public applications. Mandated by congress, the FAA will select six UAV test sites in December 2012. As required by 2012 FA reauthorization, these test sites will provide valuable data for safe, timely and efficient integration of UAVs into the nation's airspace by 2015. Establishing one of these sites in the State of Georgia would provide an opportunity to explore the benefits and capabilities of UAVs for the operations and practices within the *Georgia Department of Transportation (GDOT)*.

Aligned with FAA goals of efficient integration of UAVs into the nation's airspace, an in-depth feasibility study will be performed to determine the potential applications of UAVs within each division or associated offices across GDOT. This process starts with investigating the user requirements of each identified division/office and would lead to the development of a UAV specifications matrix based on UAV design characteristics

that fulfills the identified requirements. Finally a cost benefit analysis will be performed to compare the UAV design and construction, maintenance, and operation cost against any potential cost savings due to performance enhancement of current GDOT practices. This study will help GDOT prepare a platform for efficient and economical implementation of UAV systems to accomplish the department's mission and goals. This study will also set a reference for other DOTs across country considering UAV implementation based on their own Department's requirements.

It is envisioned that this feasibility study would ideally lead to further research on design, development, and field-testing of UAVs for applications identified as beneficial to the Department. It is also envisioned that this GDOT-based user-centered study for developing UAV design characteristics will provide a platform for appropriate data collection to facilitate FAA to accurately develop UAV integration policies and certification requirements.

Objectives:

This study will investigate various divisions and offices within GDOT and determine the user requirements for specific divisions that have the potential to implement UAV technology. This will lead to a set of UAV deign characteristics that fulfill user requirements of each previously identified division. A cost benefit analysis will be finally performed to realize the finical feasibility of applying UAV technology in each selected division within GDOT. In summary the goals of the study include:

1. To Identify user requirements for each division/office in GDOT that has the potential to benefit from UAVs.
2. To identify UAV design characteristics based on the user requirements for each GDOT division/office.
3. To perform a cost benefit analysis, comparing the UAV design and construction, maintenance, and operation cost against potential cost savings due to performance enhancement in specific GDOT department practices.

Work Plan:

Systems have traditionally been designed and developed through a technology-centered perspective (Endsley et al., 2003). In such a perspective the designers would accept the technology as is and would try to apply the very same technology in different domains without considering the very important element of the ultimate end-user (humans). In a technology-centered perspective, the end user and all its requirements would be considered improperly identical in different domains. In this research, a user-centered approach will be employed. Unlike the technology-centered approach, the very first issue that should be resolved in a user-center perspective is whether the technology is usable considering the real users' experience and their own requirements in a specific domain. This user-centered usability-based step would provide a grounded base for understanding the requirements for practical application of the technology in a domain. Having the UAV technology might seem very useful for most GDOT practices but the very first issue that should be resolved is whether this technology would be usable for different applications within GDOT divisions and offices. A usable UAV system should be designed firstly by investigating the user requirements across all divisions and offices of GDOT and then identifying and developing a set of design characteristics for the UAV based on the previously identified user requirements. Even when a real UAV is designed based on user requirements, it should be tested using real users of the system to evaluate its applicability and usability.

The work plan of this research has been illustrated in Figure 3 and the related activities are described next. The whole research encompasses four phases of;

1. Analysis of GDOT divisions/offices
2. Identification of user's operational requirements in each identified division/office
3. Identification of UAV design characteristics for each identified division/office
4. Cost-benefit analysis for each identified division/office based on the proposed UAV for that division/office.

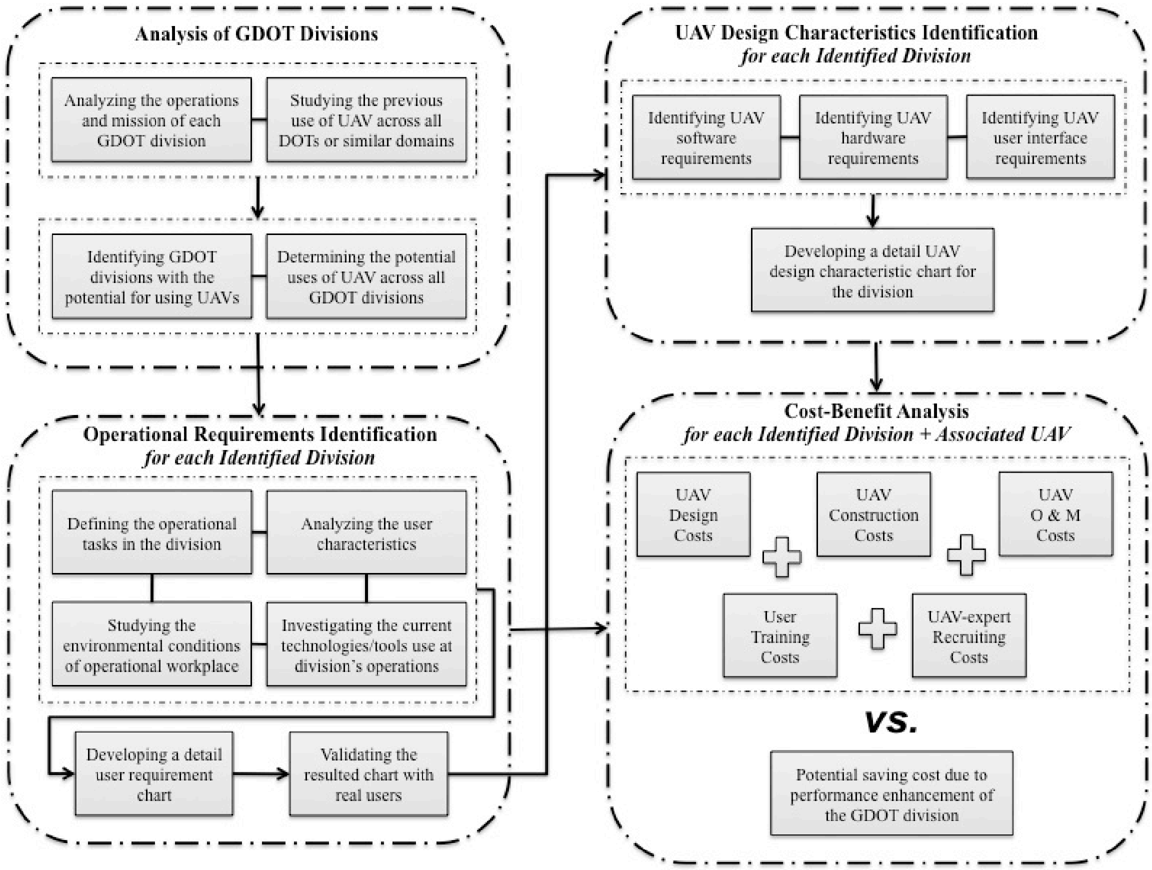


Figure 3. *Work plan flowchart*

Phase 1: Analysis of GDOT Divisions

All divisions and offices of the GDOT would be studied to identify the ones that have the potential for using UAVs. This analysis is performed by investigating the operations, mission and sets of responsibilities that each division and their internal offices might have. Furthermore, interviewing directors or administrators of each division or office would help to build a clearer picture of what would be general goals and tasks of different divisions and offices.

A simultaneous study will be started on investigating previous use of UAV across all DOTs together with determining the current status of different civil applications of UAV. A detailed review of various DOTs' materials and reports together with a study of up-to-date publications and research on UAV civil application will be performed. This will lead

to a set of case studies and application areas and provide a good start point for visualizing GDOT's roadmap for UAV implementation. Having a clear understating of what other DOTs have done and determining the current status of civil application of UAVs would help when identifying different divisions of GDOT with potential of applying UAVs. Those case studies and application areas would help the directors and administrators of GDOT divisions and offices to build a clear picture of how UAVs have been previously utilized so they as experts in the division would provide more valid feedback in their interviews.

The result of this phase would lead to identifying different GDOT divisions with the potential for using UAVs as well as determining the potential uses of UAV across all GDOT divisions.

Phase 2: Operational Requirement Identification *(for each identified division)*

In the this phase the broad goals and objectives of the each identified division would be translated into a set of requirements that should be considered for designing a specific UAV for that division. This analysis will include four different considerations: (1) defining the operational tasks in the division, (2) studying the environmental conditions of operational workplace, (3) analyzing the user characteristics, and (4) investigating the current technologies/tools use at division's operations.

(1) Defining the operational tasks in the division: The very first and the most important issue in this phase is to study the tasks and operations preformed in the identified division to develop exact definitions of those tasks and operations as well as their scope. In this research, an adapted form of cognitive task analysis, Goal Directed Task Analysis (GDTA), will be used for this purpose (Bolstad et al., 2002). The GDTA will be employed broadly for analysing the tasks and operations in the identified divisions and for determining requirements of individuals performing those tasks and operations (Endsley, 1993, Endsley and Rodgers, 1994). The GDTA follows a set of semi-structured interviews with Subject Matter Experts (SMEs) in each identified division and focuses on (1) the basic goals of the operators in each division, (2) their major decisions for

accomplishing those goals, and (3) the information requirements for each decision. The information obtained from the GDTA is organized into figures depicting a hierarchy of the three main components of the GDTA (i.e., goals/subgoals, decisions relevant to each subgoal, and the associated information requirements for each decision). The research team has worked with the proposed method for determining the information requirements of safety managers and well as those of facility managers in Architecture, Engineering, and Construction organizations (Gheisari and Irizarry, 2011, Gheisari et al., 2010b, Gheisari et al., 2010a)

(2) Studying the environmental conditions of operational workplace: The other important issue that should be studied together with operational requirements is the environmental conditions in which the tasks/operations occur in each identified GDOT division. These environmental conditions would affect the design requirement of the UAV. Ambient noise levels, lighting levels, susceptibility to weather and temperature variations, vibration, privacy, expected pace of operations, position of use (e.g., sitting, standing, while mobile), and frequency of use (e.g., occasional, intermittent, frequent, continuous), are some issues that should be considered as the environmental conditions (Endsley et al., 2003).

(3) Analyzing the user characteristics: The user characteristics will be identified in this phase. The different types of users that this system would accommodate should be discussed considering issues such as gender (male, female, or both), anthropometric characteristics, including height and weight (percentile of the population to be accommodated), skill level, training, and background knowledge (including technical capability and experience with similar types of systems), age ranges (with special note of young or aging populations), visual acuity and hearing capabilities, languages to be accommodated, special clothing or other equipment to be accommodated (such as gloves, masks, or backpacks), any physical disabilities or special requirements, and the need to accommodate multiple users on the same system (Endsley et al., 2003).

(4) Investigating the current technologies/tools use at division's operations: Here all different technologies or tools that are being used by the identified division will be evaluated for possible integration with the UAV platform. There might be a need for integrating hardware (e.g. sensors, radars, or different type of cameras) with the UAV hardware or software. Also, the user interface might be required to incorporate or be compatible with other technologies that are currently used by GDOT in the identified division (e.g. energy or traffic software).

This phase of the study will lead to a detail operational requirement matrix considering each division's operation, user characteristics, working environment, and technology use. This matrix would be taken back to the SMEs who were interviewed in Part 1 of Phase 2 (*Defining the operational tasks in the division).* An unstructured interview will take place to identify missing information and errors in the matrix and validate its outcomes.

Phase 3: UAV Design Characteristics Identification *(for each identified division)*

This phase will entail determining requirements on the UAV system necessary to meet GDOT needs for each identified division. These requirements will entail software, hardware, and the user interface. Under this effort, off the shelf UAV systems will also be identified that partially or completely meets requirements. It will be important not to limit this effort to existing vehicle systems, given how new this industry is. However, existing systems can be the basis to validate stated requirements as feasible and cost estimates described below. In addition, this will be an important basis for identifying the risks associated with meeting stated requirements.

Phase4: Cost-Benefit Analysis *(for each identified division)*

In this phase, a cost-benefit analysis will be performed. On one side, the total cost of the UAV implementation and use in each identified GDOT division will be studied. This total cost consists of design, construction, operation & maintenance costs of the UAV and the costs for training the users at the division for its efficient use and also the possible cost of recruiting UAV experts to work for GDOT. All these costs will be compared against the potential cost savings due to performance enhancements in GDOT practices.

The basis of UAV operation cost estimates will be based on current Georgia Tech UAV Research Facility operations, information provided on currently available systems, and publically available information. Reporting will include an evaluation of the uncertainty in these cost estimates. We will also point out any particular unknown parameters that may affect cost estimates.

During the course of the project, progress meetings will be held in accordance with GDOT regulations. The proposed meeting schedule is included in the Work Plan Schedule section.

Expected Results:

The expected results of the project are:

1. An in-depth understating of the current status of UAV application across various DOTs in the US and determining the current status of different civilian applications of UAV technology.
2. Determining the operational requirements for each identified GDOT division/office considering its operation, user characteristics, working environment, and technology use.
3. Determining the UAV design characteristic for each identified GDOT division/office which is mapped with operational requirements (result of Phase 2)
4. A cost-benefit analysis of the recommended UAV (result of Phase 3) for each identified GDOT division/office. The result would show whether UAV application in that division/office can be financially justified or not.

Deliverables:

The deliverables for this project will include the following and they will be delivered as per the Proposed Work Plan Schedule included in Appendix A:

1. A comprehensive matrix of user requirements that is mapped with the UAV design specifications for each identified GDOT division/office.

2. A final project report detailing all project phases (divisions/offices in GDOT with potential to apply UAV, operational user requirement analysis for each division/office, UAV design characteristics, and associated cost-benefit analysis)

Implementation:

The results of the proposed study have the potential for implementation at GDOT by providing the foundation for financial justification of UVA implementation as well as the foundation for technical requirements and application definition in applicable Divisions and Offices. The results will also provide GDOT with potential participation in efforts to provide detailed data to the Federal Aviation Administration efforts on policy for safe, timely and efficient integration of UAVs into the nation's airspace.

Budget Estimate:

The total project budget is $74,984. The following budget estimate shows the distribution of the project costs by project year and project phase/task:

Budget Estimate: Total Project Budget	
	YEAR 1
1. Salaries and Wages	
PI Javier Irizarry (17% time, Y1)	12,240
Co-PI Eric Johnson (12% time Y1)	13,375
GRA(1 PhD stud@50%,12M, Y1)	22,380
TOTAL PERSONNEL COSTS	47,995
2. Staff Benefits and Payroll Taxes	
=27.9% (PI and Co-PI)	7,147
1.8% (Student health insurance)	403
TOTAL BENEFITS	7,549
3. Equipment	0
TOTAL EQUIPMENT COSTS	0
4. Materials and Supplies	0
TOTAL M&S COSTS	0
5. Communications Expense	0
TOTAL COMM COSTS	0
6. Travel	0
TOTAL OTHER COSTS	0
7. Subcontracts	0
TOTAL SUBAWARDS	0
8. Overhead	19,440
35% - excluding equipment >$5000	
TOTAL FUNDS REQUESTED	**$74,984**

Budget Estimate	
Phase 1	**YEAR 1**
1. Salaries and Wages	
PI Javier Irizarry (4% time, Phase 1)	2,880
Co-PI Eric Johnson (3% time, Phase 1)	3,344
GRA(1 PhD stud 10% time, Phase 1)	4,476
TOTAL PERSONNEL COSTS	10,700
2. Staff Benefits and Payroll Taxes	
=27.9% (PI and Co-PI)	1,736
1.8% (Student health insurance)	81
TOTAL BENEFITS	1,817
3. Equipment	0
TOTAL EQUIPMENT COSTS	0
4. Materials and Supplies	0
TOTAL M&S COSTS	0
5. Communications Expense	0
TOTAL COMM COSTS	0
6. Travel	0
TOTAL OTHER COSTS	0
7. Subcontracts	0
TOTAL SUBAWARDS	0
8. Overhead	4,381
35% - excluding equipment >$5000	
TOTAL FUNDS REQUESTED	**$16,897**

Budget Estimate	
Phase 2	**YEAR 1**
1. Salaries and Wages	
PI Javier Irizarry (4% time, Phase 2)	2,880
Co-PI Eric Johnson (3% time, Phase 2)	3,344
GRA(1 PhD stud 15% time, Phase 2)	6,714
TOTAL PERSONNEL COSTS	12,938
2. Staff Benefits and Payroll Taxes	
=27.9% (PI and Co-PI)	1,736
1.8% (Student health insurance)	121
TOTAL BENEFITS	1,857
3. Equipment	0
TOTAL EQUIPMENT COSTS	0
4. Materials and Supplies	0
TOTAL M&S COSTS	0
5. Communications Expense	0
TOTAL COMM COSTS	0
6. Travel	0
TOTAL OTHER COSTS	0
7. Subcontracts	0
TOTAL SUBAWARDS	0
8. Overhead	5,178
35% - excluding equipment >$5000	
TOTAL FUNDS REQUESTED	**$19,973**

Budget Estimate	
Phase 3	**YEAR 1**
1. Salaries and Wages	
PI Javier Irizarry (5% time, Phase 3)	3,600
Co-PI Eric Johnson (3% time, Phase 3)	3,344
GRA(1 PhD stud 15% time, Phase 3)	6,714
TOTAL PERSONNEL COSTS	13,658
2. Staff Benefits and Payroll Taxes	
=27.9% (PI and Co-PI)	1,937
1.8% (Student health insurance)	121
TOTAL BENEFITS	2,058
3. Equipment	0
TOTAL EQUIPMENT COSTS	0
4. Materials and Supplies	0
TOTAL M&S COSTS	0
5. Communications Expense	0
TOTAL COMM COSTS	0
6. Travel	0
TOTAL OTHER COSTS	0
7. Subcontracts	0
TOTAL SUBAWARDS	0
8. Overhead	5,501
35% - excluding equipment >$5000	
TOTAL FUNDS REQUESTED	**$21,216**

Budget Estimate	
Phase 4	**YEAR 2**
1. Salaries and Wages	
PI Javier Irizarry (4% time, Phase 4)	2,880
Co-PI Eric Johnson (3% time, Phase 4)	3,344
GRA(1 PhD stud 10% time, Phase 4)	4,476
TOTAL PERSONNEL COSTS	10,700
2. Staff Benefits and Payroll Taxes	
=27.9% (PI and Co-PI)	1,736
1.8% (Student health insurance)	81
TOTAL BENEFITS	1,817
3. Equipment	0
TOTAL EQUIPMENT COSTS	0
4. Materials and Supplies	
TOTAL M&S COSTS	0
5. Communications Expense	0
TOTAL COMM COSTS	0
6. Travel	
TOTAL OTHER COSTS	0
7. Subcontracts	0
TOTAL SUBAWARDS	0
8. Overhead	4,381
35% - excluding equipment >$5000	
TOTAL FUNDS REQUESTED	**$16,897**

Cooperative Features:

Assistance from GDOT will be requested during the project, in terms of coordination for GDTA interviews. This collaboration entails providing contact information for the leadership of the GDOT Divisions and Departments that will participate in the study.

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Appendix A. Work Plan Schedule:

The project duration is 12 months. The following figure shows the proposed schedule for the 12-month project:

Tasks	Duration	Months											
		1	2	3	4	5	6	7	8	9	10	11	12
Phase 1 Assessment of GDOT Divisions and Offices (High Level Interviews)	3 months												
Phase 1 Review of past and current UAV applications	2 months												
Phase 2 (1) Defining the operational tasks in the division (GDTA)	3 months												
Phase 2 (2) Studying the environmental conditions of operational workplace	3 month												
Phase 2 (3) Analyzing the user characteristics	3 month												
Phase 2 (4) Investigating the current technologies/tools use at division's operations	3 months												
Phase 3 UAV Design Characteristics Identification	3 month												
Phase 4 Cost-Benefit Analysis	3 months												
Final Report Preparation	2 months												
Final Report Review and Revision	3 months												
Kickoff and Quarterly Project Progress Meetings													
Quarterly Reports and Final Report													

Figure 3 Proposed Work Plan Schedule

Appendix B. Supporting Information:

, Ph.D., P.E.

, Ph.D. Civil Engineering, Purdue University. Dr. Irizarry is a Professional Engineer who has experience in the planning and construction of multiple types of infrastructure facilities including but not limited to PCC highways, bridges, and parking structures while working for Redondo Construction Corporation in Puerto Rico from 1997 to 2001. Dr. Irizarry has conducted research in the areas of construction safety, information technology in construction, digital tools for construction-related education and in the applicability of computer applications for constructability analysis in pavement rehabilitation (CA4PRS), information needs assessment for role-based tasks, and use of unmanned aerial vehicles (UAVs) for construction applications. Dr. Irizarry is a faculty member in the School of Building Construction at the Georgia Institute of Technology.

Related Work:

Irizarry, J., *Gheisari, M. & Walker, B. N. 2012. Usability assessment of drone technology as safety inspection tools. Journal of Information Technology in Construction (ITcon). Vol. 17, pg. 194-212

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